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Navy Department
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Preliminary Report

RESISTANCE TESTS ON
A SERIES OF FLAT NOSE BODIES
THE 6-IN. PROJECTOR CHARGE
THE 5-IN. A.S. PROJECTILE

By

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Introduction

As a part of the program to study high sinking rate shapes, a series of drag tests was run in the High Speed Water Tunnel. Since flat noses are used to facilitate water entry, a preliminary investigation was made of the drag of flat nosed bodies of varying bluntness. The study as planned will later include streamline shapes. Drag measurements were also obtained for the 6-in. Projector Charge Ex. 1 and the 5-in. A.S. Projectile Ex. 30.

Results of Initial Tests with Varying Nose Bluntness

The tunnel drag tests were conducted on bodies with truncated 9-calibre ogive noses, cylindrical center sections, and smoothly faired Lyons Form[1]* afterbodies with fins.

Two series of models were utilized. The first series was obtained by progressively truncating the nose of the model and simultaneously increasing the length of the cylindrical midsection to produce constant length models with various diameter flat noses, (Fig. 1). The model nose varied progressively from a pointed ogive to a flat nosed cylinder.

The second series was achieved by progressively truncating the nose and adjusting the length of the midsection to maintain constant volume.

Drag coefficients vs. Reynolds numbers were obtained for the models of varying bluntness and are plotted on Figs. 2 and 3. All Reynolds numbers shown are based on the length of the models.

Calculated Sinking Rates from Model Data

From the water tunnel data obtained on the flat nosed models, calculations of maximum sinking rate were made. Fig. 4 is a plot of terminal sinking rate vs. bluntness for various volumes. Each curve shown represents a series of shapes that is geometrically similar to the shapes used in the water tunnel. The curves are plotted for a range of volumes from 0.4 to 5 cubic feet and calculated for a density of 117.6 lbs per cubic foot which is equal to that of Weapon A.[2]

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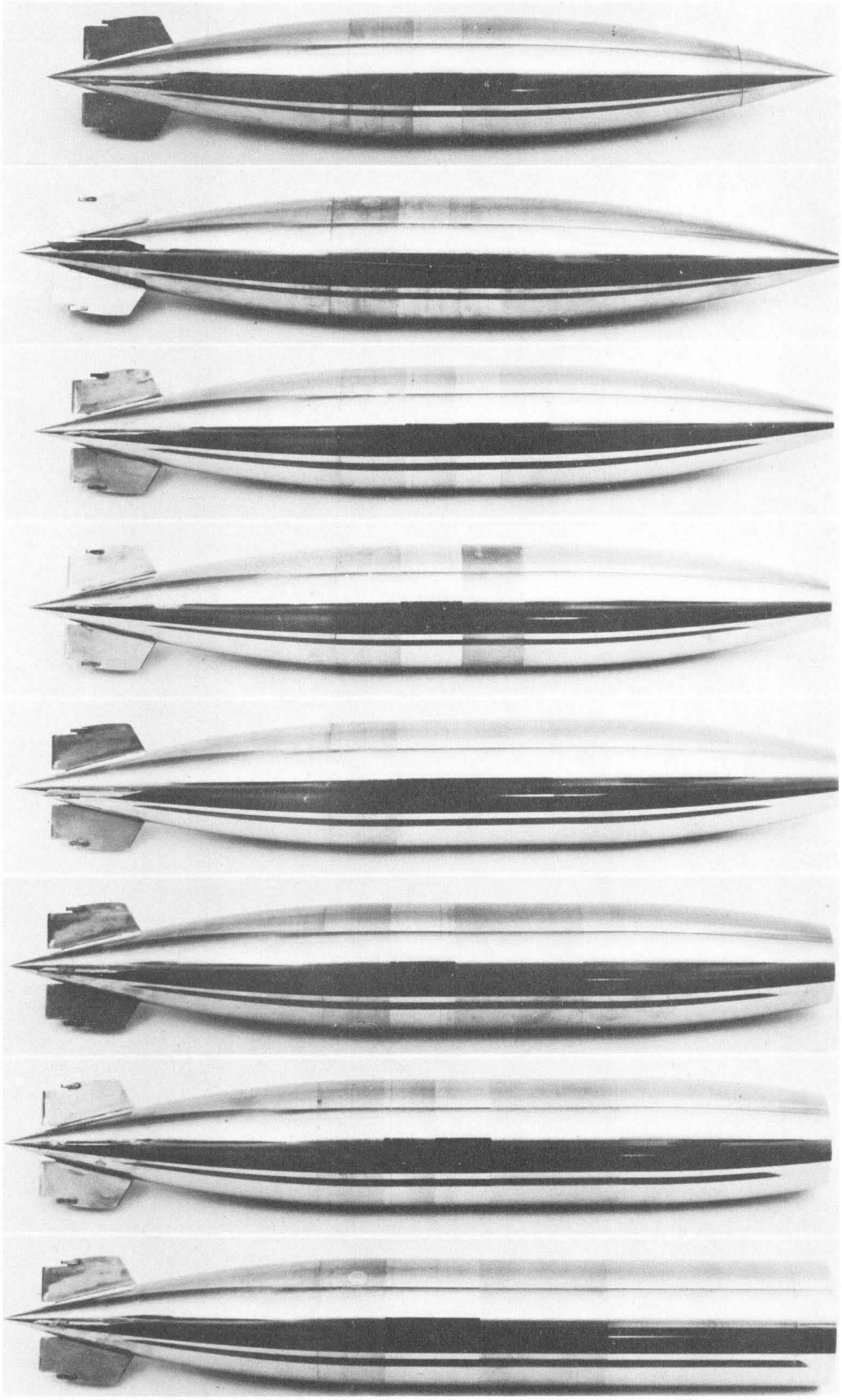
* Numbers in parentheses refer to bibliography at end of this report.



Model

A

B

C

D

E

F

G

H

Fig. 1 - Constant length model series with truncated 9-calibre ogive nose and Lyons Form afterbody

ℓ = 13.20 in.; d = 2.00 in.

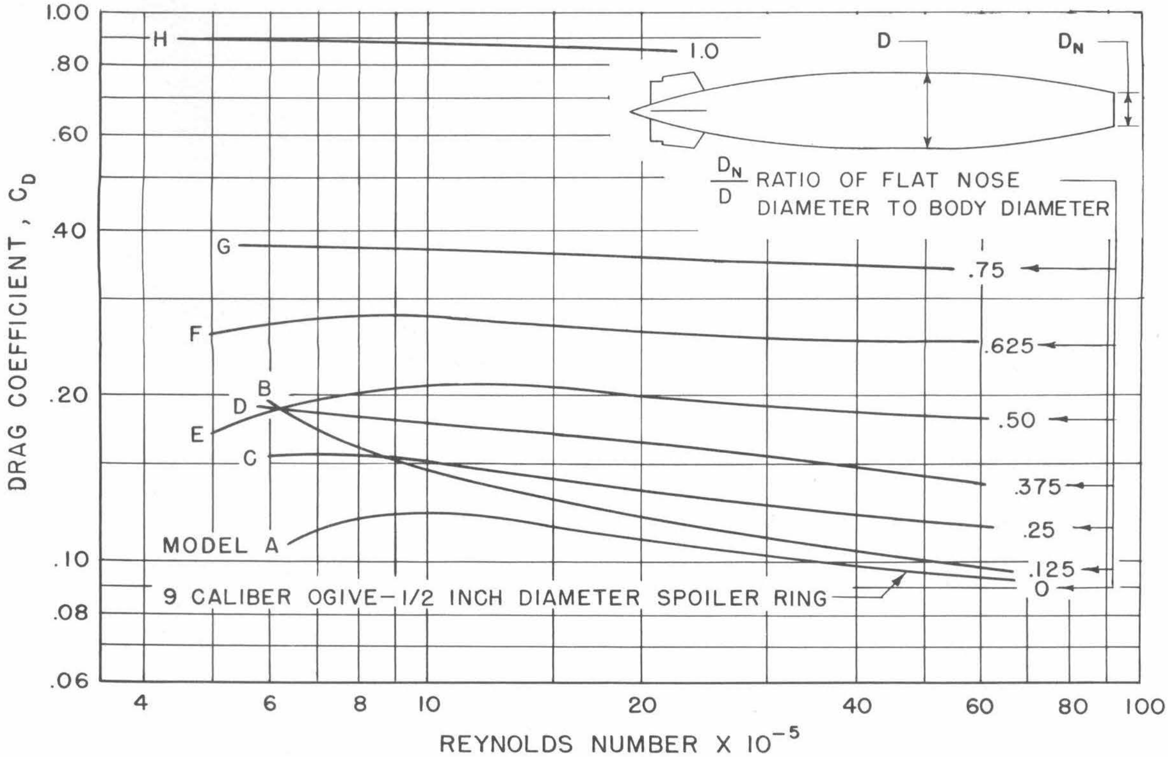


Fig. 2 - Drag coefficient vs. Reynolds numbers for varying degrees of bluntness for a constant length body

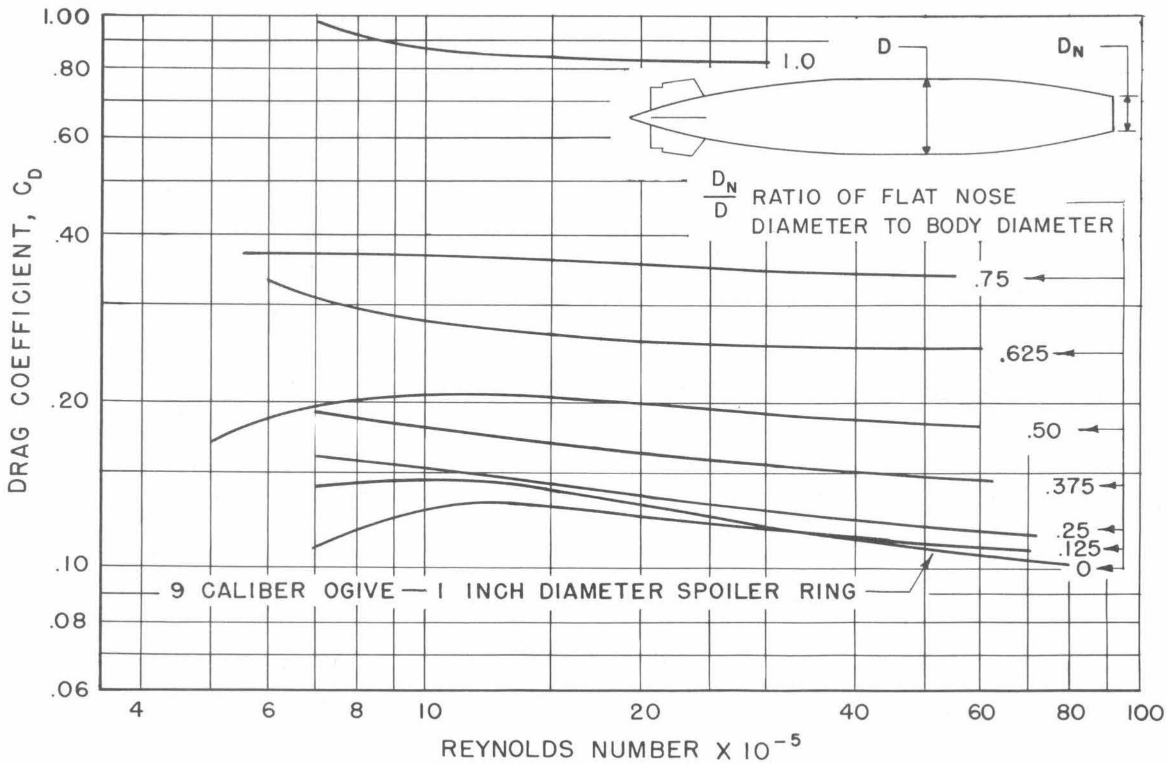


Fig. 3 - Drag coefficient vs. Reynolds numbers for varying degrees of bluntness for a constant volume body

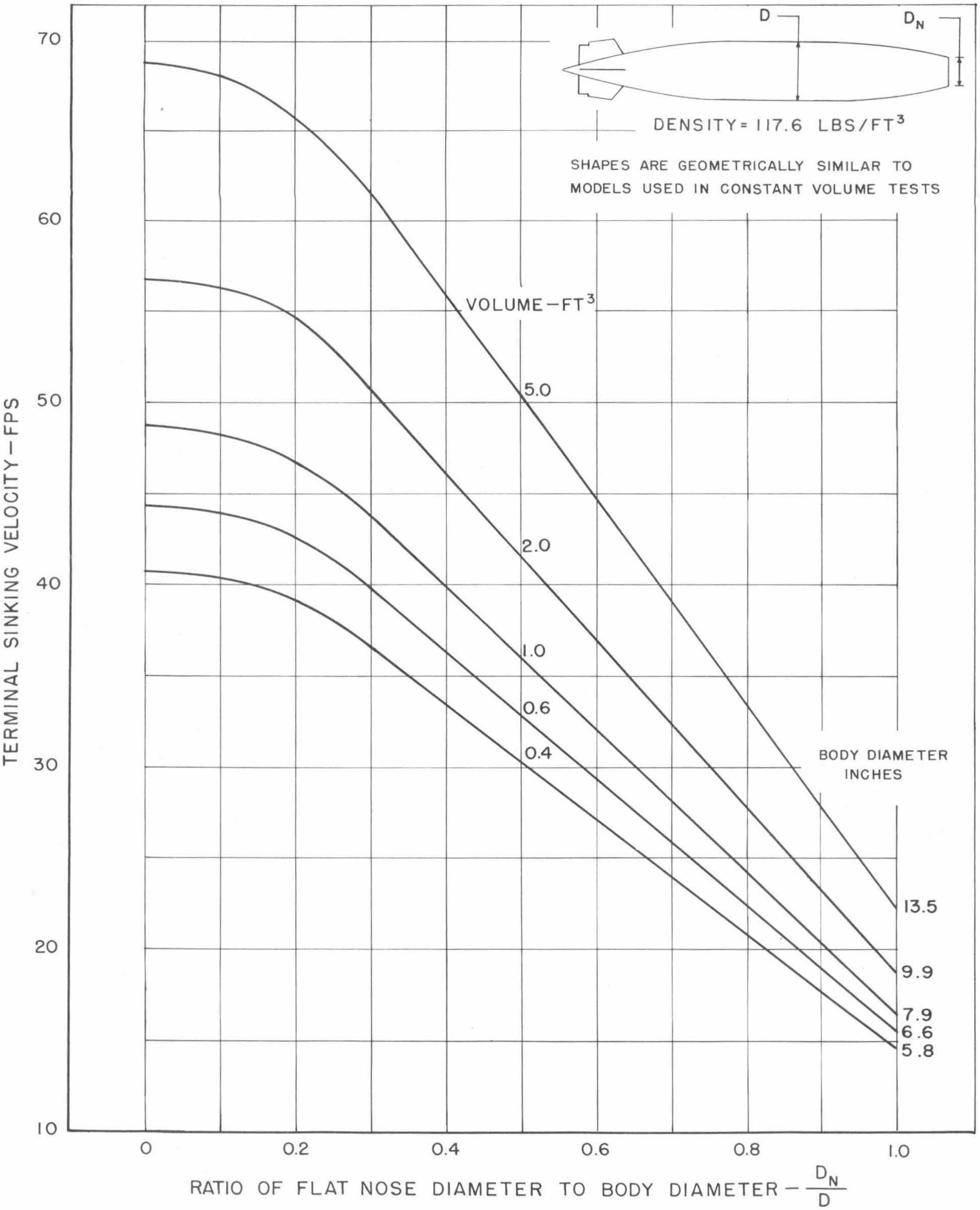


Fig. 4 - Terminal sinking velocity as a function of bluntness for several projectile volumes

Slenderness Ratio vs. Sinking Rate

No attempt was made to determine the effect of slenderness ratio on the sinking rate of the model shapes tested. The graph, Fig. 5, prepared from existing Hydrodynamics Laboratory data,[3] shows the effect of slenderness ratio on the terminal sinking velocity of a blunt and a streamline shape of constant volume. Although the fine shape has a maximum sinking rate at a slenderness ratio of approximately 14, the blunt nose body shows sinking rate increasing with slenderness ratio for all lengths shown. The data obtained in the tunnel were for a blunt body with a slenderness ratio of approximately 7. The apparent drag penalty due to bluntness, as shown in Fig. 4, can be greatly reduced by increased slenderness ratio. As the bluntness increases, the optimum slenderness ratio for maximum sinking rate should increase due to changes in relative amounts of skin friction and form drag.

Effect of Density and Volume on Sinking Rate

Large variations in sinking rate result from differences in volume and density and are illustrated in graphs, Figs. 6 and 7. Fig. 6 shows terminal sinking velocity as a function of volume with a constant density equal to that of Weapon A, while Fig. 7 shows sinking rate as a function of density for a body with volume equivalent to that of Weapon A. Both curves are for a projectile with a 6-to-7-calibre length, a 1/2 calibre flat on an ogive nose and a Lyons Form afterbody.

Afterbody Shape vs. Resistance

The rocket motor tube afterbody such as used on Weapon A, although required by design considerations, causes a drag penalty when compared with a fine afterbody shape. Experimental drag measurements were made on models of equal length, with the original Weapon A nose and three different afterbodies. The results are shown in Fig. 8 which presents the curves of drag coefficient vs. Reynolds number. The afterbodies used were the original Weapon A, the modified ogive, and the Lyons Form as shown in Fig. 9. The fin area of the model tails varied from 5.7 $in.^2$ for the modified ogive to 6.6 $in.^2$ for Lyons Form. No consideration was

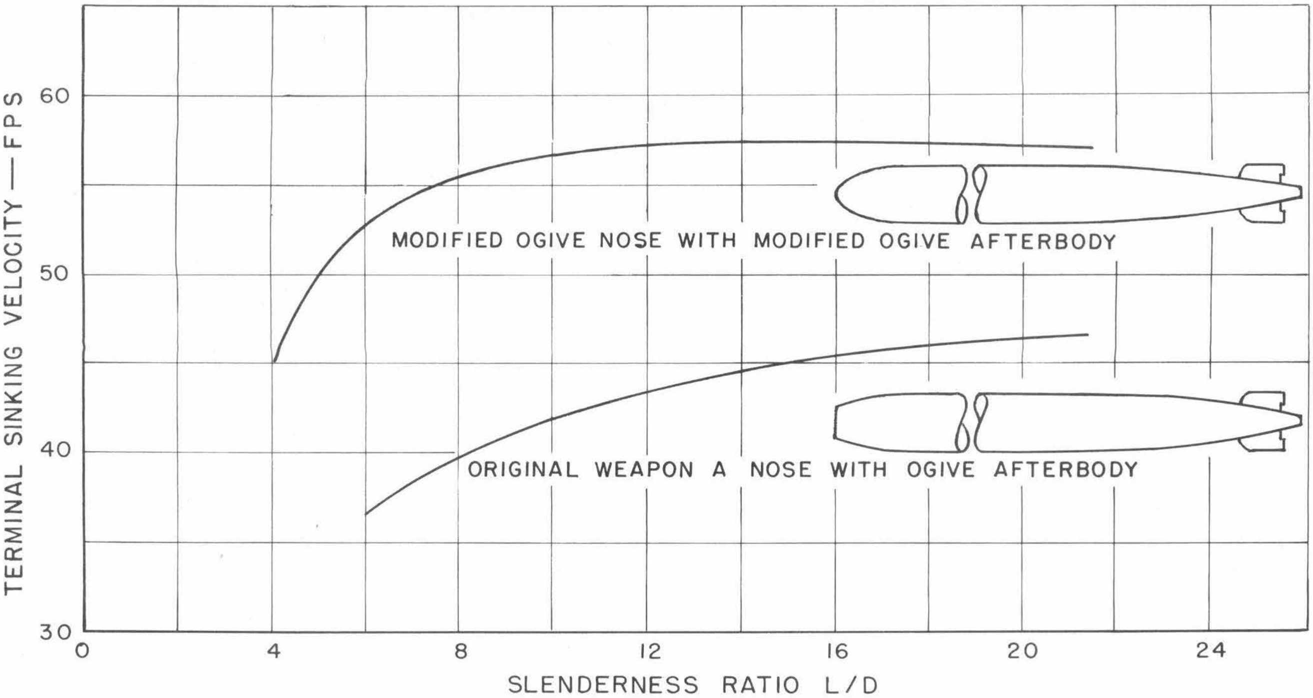


Fig. 5 - Sinking velocity vs. slenderness ratio for bodies with cylindrical midsections

Volume = 4.11 ft^3; Density = 117.6 lbs/ft^3

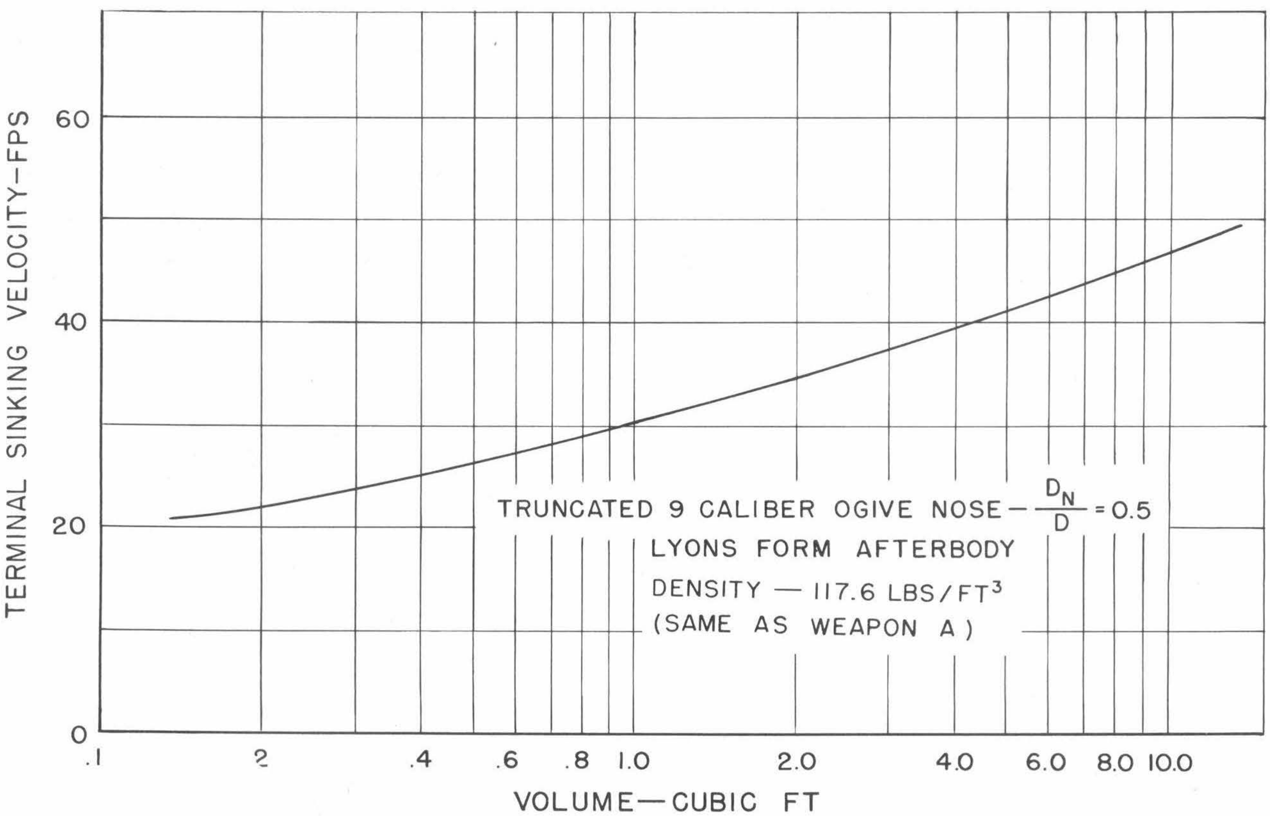


Fig. 6 - Sinking velocity vs. volume

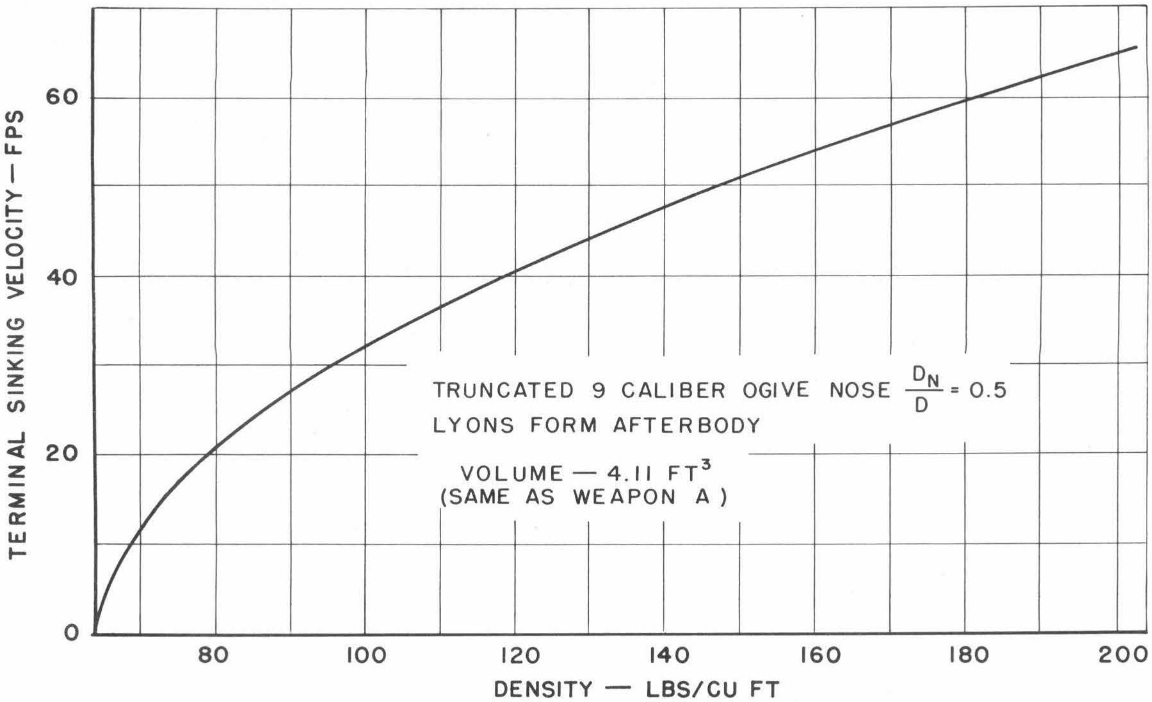


Fig. 7 - Sinking velocity vs. density

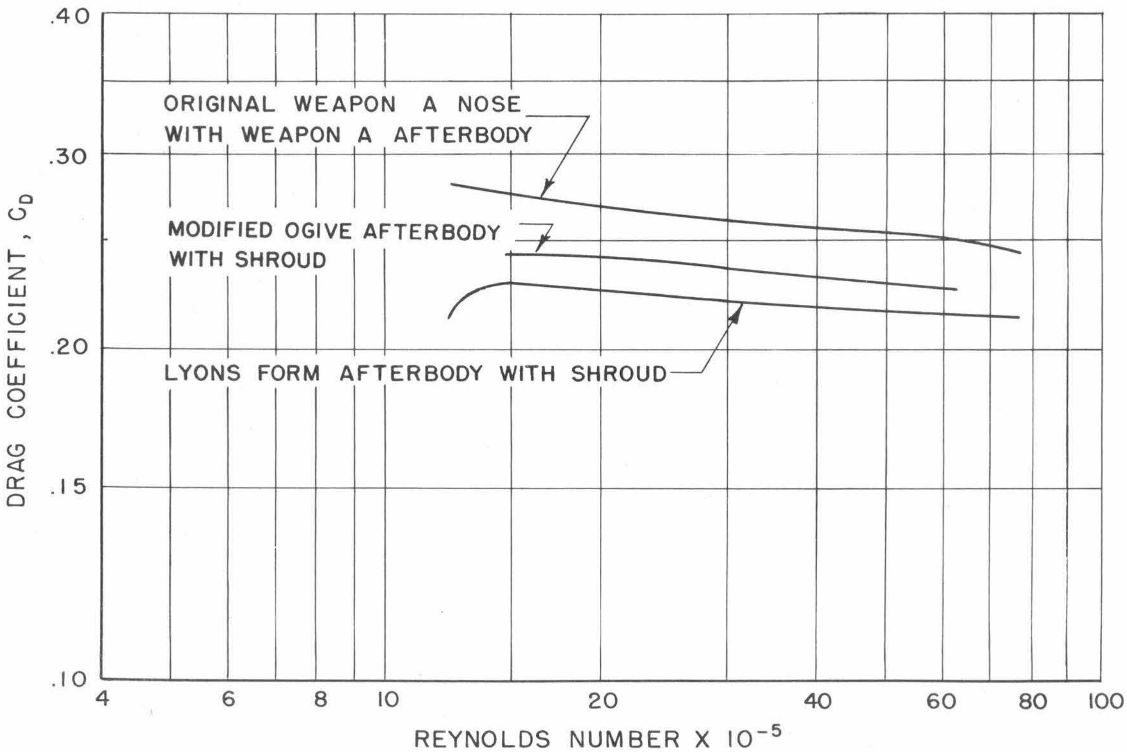


Fig. 8 - Effect of afterbody shape on drag coefficient

given to the fin area necessary for stability of these shapes. When compared on a basis of volume and density the same as Weapon A, the terminal sinking velocities obtained are 31.9 fps for Weapon A,[4] 38.1 fps for the body with modified ogive afterbody, and 38.8 fps for the shape with Lyons Form afterbody. As expected, greater sinking rates are obtained with the fine afterbodies though considerations of a propulsion or launching system may dictate the adoption of some other type. It will be noted that the very fine Lyons Form produces a slight improvement in sinking rate when compared with the modified ogive afterbody.

Tests on 6-in. Projector Charge and 5-in. A.S. Projectile

In addition to the above tests, drag runs were made with 2-in. diameter models of the 6-in. Projector Charge Ex. 1 (BuOrd sketch No. 239308) and the 5-in. A.S. Projectile Ex. 30 (BuOrd sketch No. 239585) at the request of Dr. A. Miller, BuOrd. These resistance tests were made both for the flat nose models and with the armed EX 102 nose fuse with vanes jettisoned. Both models, Fig. 10, were made with fins at an angle of attack of zero degrees instead of the 10- and 7-degree fin angles shown in the BuOrd sketches.

The results of these runs are shown in Fig. 11 and indicate a variation in drag value caused by the test equipment. The High Speed Water Tunnel balance is of the type that does not differentiate between drag and pitching moment. This does not cause trouble with models of average length and shape, but it is likely to cause errors with models of unusual length such as the two tested. To determine if pitching moment was affecting drag readings, the support point was shifted from the 0.50 L. point to the 0.33 L. point and a 22% difference of drag reading was observed with the 6-in. Projector Charge. Further check tests will be run to eliminate this discrepancy. Using data obtained with the body supported at the 0.50 L. point, terminal velocities were calculated to be 31.2 fps for the body without fuse and 32.9 fps for the armed nose fuse projectile. For the 33% support point similar calculations gave sinking rates of 36.6 and 38.8 fps, respectively. Tests of these shapes conducted at the Alden Hydraulic Laboratory[5] indicated a drag coefficient of 0.280 with

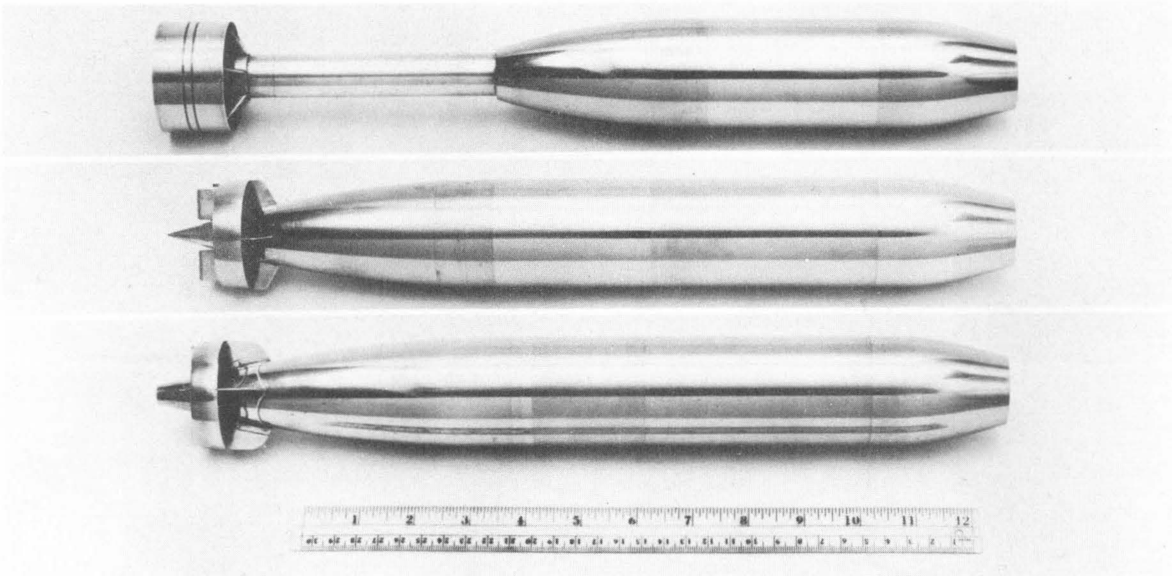


Fig. 9 - Models with original Weapon A nose and various afterbodies
Top - Weapon A; Middle - Lyons Form; Bottom - Modified ogive

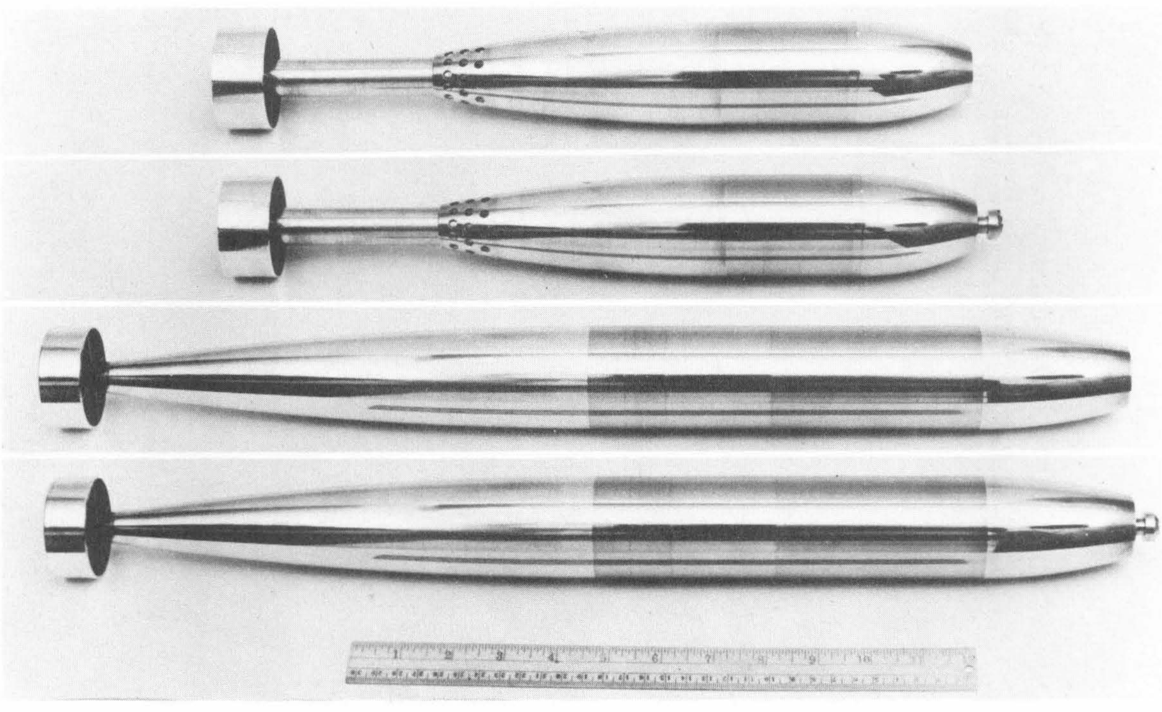


Fig. 10 - 2-in. diameter models of the 6-in. Projector Charge, Ex. 1 (top) and the 5-in. A.S. Projectile, Ex. 30 (bottom)

flat nose and 0.185 with armed nose fuse. Sinking rates were calculated by the Hydrodynamics Laboratory using the Alden data and were found to be 27.2 and 33.4 fps respectively.

The 5-in. A.S. Projectile was calculated to have a terminal sinking velocity of 38.2 fps with armed nose fuse and 35.5 fps without fuse. This sinking rate is in agreement with that obtained in launching tests at the Alden Hydraulic Laboratory(6) which showed a drag coefficient of 0.30 for the flat nose model operating without a cavity. If this result is used, the calculated terminal sinking rate is 35.0 fps.

Discussion

The goal of the optimum sinking rate program, as expressed in correspondence with members of the Bureau of Ordnance, is to develop body shapes which will have sinking velocities approximately twice that of Weapon A. The body shapes tested to date at this and other laboratories fall far short of this goal.

By means of simple calculations it is possible to find an upper bound for the sinking rate of a given body and to obtain an idea of the degree of improvement attainable through refinements in the hydrodynamic design of such a body. In addition, one can obtain some approximate information about the dependence of the terminal velocity of a body on its size and weight. Because in making such calculations it is assumed that the body experiences only skin friction, the information obtained has only the nature of an optimistic estimate.

In general, the total drag of a body immersed in a fluid is composed of skin friction and form drag. Both of these factors exhibit marked variations with the Reynolds number. We shall suppose that the bodies considered in this discussion have a form drag which is very small compared to the skin friction, and that for all Reynolds numbers to be considered, the drag coefficient C_D, based on the wetted surface area is given, for turbulent skin friction, by(7)

$$C_D = \frac{.072}{R^{1/5}}$$

where R is the Reynolds number referred to the body length. This relation for the total drag approaches reality only for very slender highly refined shapes when the boundary layer flow is turbulent.

At the terminal velocity, the sum of all forces, and hence the acceleration, is zero. The forces which oppose the motion are drag and buoyancy, while the force of gravity acts in the opposite direction. If one writes the surface area A, and the volume V, as $A = k_A \ell^2$, $V = k_V \ell^3$ where ℓ is the body length, and equates the gravity force to the resistance and buoyant forces, one finds at once that the terminal velocity has the upper bound

$$v_T = \left[\frac{(w - 1)\, g\, k_V \ell^{6/5}}{.036\, \nu^{1/5}\, k_A} \right]^{5/9}$$

where w is the specific gravity of the body

g is the accleration of gravity, ft/sec^2

and ν is the kinematic viscosity of the water. ft^2/sec

If only the length varies, then $v_T \propto \ell^{2/3}$, and if only the weight is changed then $v_T \propto (w - 1)^{5/9}$. If, for an actual case, the terminal velocity is known, it may be possible to use these relations to obtain first approximations to the terminal velocity of a given shaped body for other weights and lengths.

In order to investigate the possible degree that the sinking rates of existing weapons may be increased by refining the body shape, we shall compute the upper bound on the terminal velocity for Weapon A[2] and for the 6-in. Projector Charge[5]. In these computations, we take the values for the physical properties of sea water at a temperature of 60° F.[8]

Weapon A:

Volume = 4.11 cu ft   Length = 8.132 ft

Weight = 483.3/cu ft

$w = 1.83$, $k_A = 0.29$, $k_V = 7.6 \times 10^{-3}$

v_T = 74 fps

<u>6-in. Projector Charge:</u>

Volume = 0.382 cu ft Length = 3.65 ft

Weight = 64.75

$w = 2.62$, $k_A = 0.29$, $k_V = 7.86 \times 10^{-3}$

$\underline{v_T = 64 \text{ fps}}$

For comparison with the above figures we cite experimentally determined values of the sinking rates of these two bodies.

Weapon A:[2] experimental sinking rate = 38 fps

6-in. Projector Charge:[5] experimental sinking rate = 33.4 fps

From the above comparison, it is clear that considerable improvement might be possible. However, in this regard, it must be noted that the requirements for stable water entry may conflict with the need for improving the streamlining of the bodies. On the other hand, the calculated variations of the sinking rate with the size and weight of the weapon would seem to indicate that, where possible, these factors may be exploited to increase the sinking rate of a given shaped body. Finally, it must be emphasized again that the values of v_T computed above represent an upper bound for the sinking rate for turbulent flow. Even though the realization of this upper bound on v_T is improbable, the present weapons fall far short of this mark. However, the use of low drag shapes for such missiles will enable actual weapons to approach this maximum sinking rate.

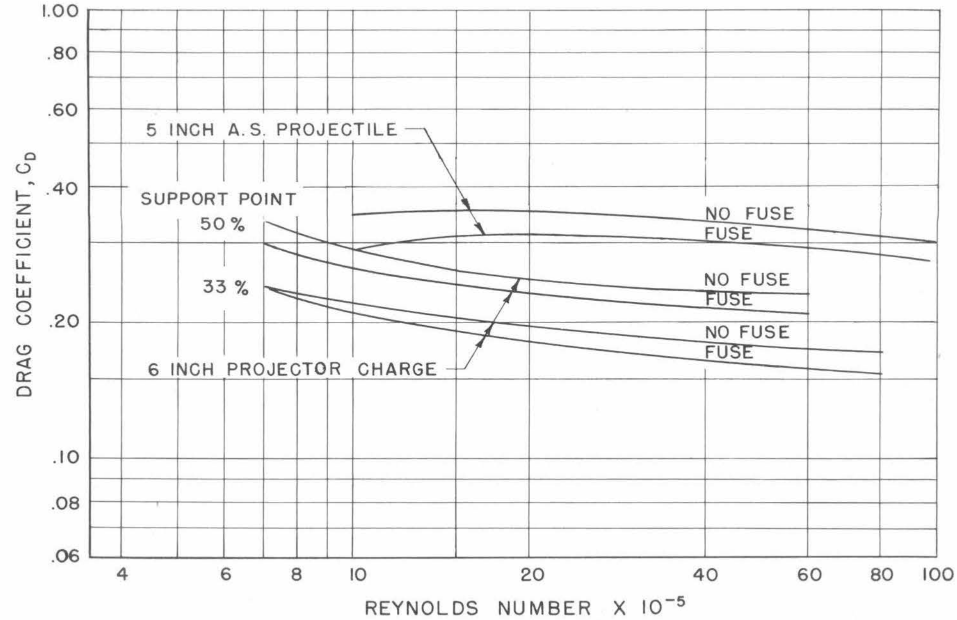


Fig. 11 - Drag coefficient vs Reynolds number for models of 6-in. Projector Charge and 5-in. A.S. Projectile

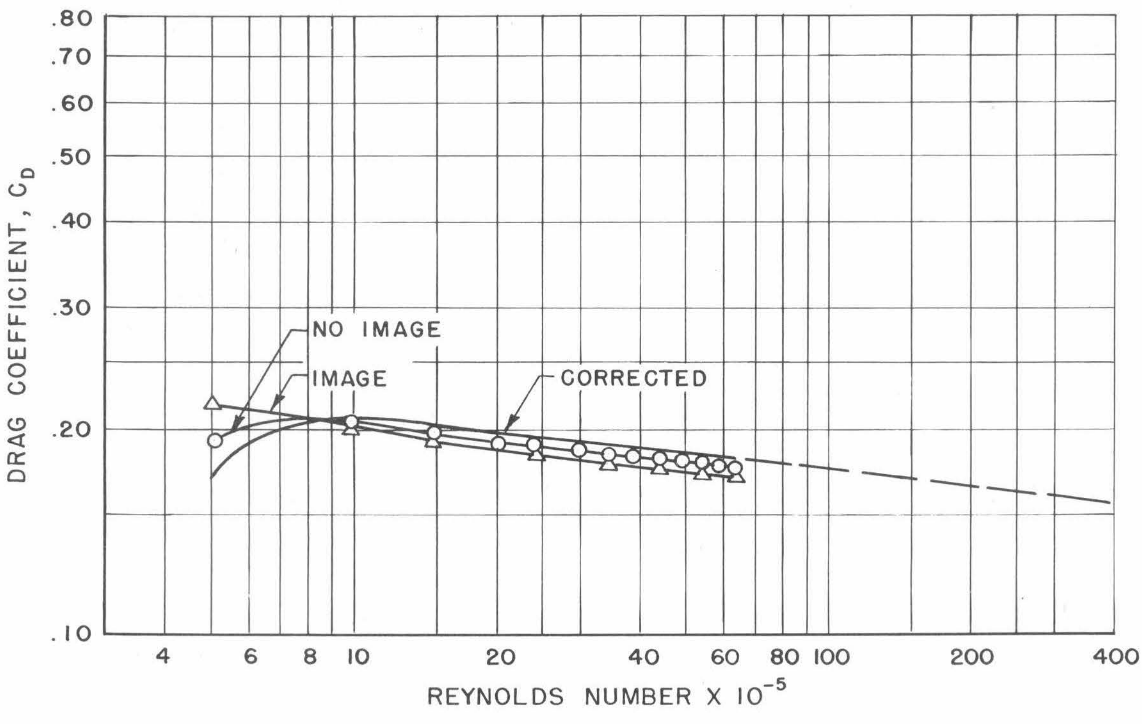


Fig. 12 - Drag coefficient vs. Reynolds number for Model E, Fig. 1

SAMPLE CALCULATIONS

(Based on Model E, Fig. 1)

I. Data Reduction

Drag coefficient was calculated directly from drag vs. velocity runs.

$$\text{Drag Coefficient} \quad (C_D) = \frac{D}{\rho/2\ A_D\ V^2}$$

D = Drag force - lbs

ρ = Density of fluid - slugs/ft^3

A_D = Area at maximum cross section of the projectile taken normal to its geometric axis - ft^2

V = Mean relative velocity between fluid and projectile - fps

Data: (no image run)

Velocity = 30.25 fps

Drag force = 3.785 lbs

Water temperature - 65.3°F giving ρ = 1.938 slugs/ft^3
ν = 11.29 x 10^{-6} ft^2/sec

A_D = 0.0218 ft^3

L = 1.1 ft

$$C_D = \frac{3.785}{1.938/2 \times 0.0218 \times (30.25)^2} = 0.196$$

Horizontal Buoyancy Correction = -0.010 (Due to working section pressure gradient)

C_D = 0.186

Reynolds number was based on the model length

$$R_e = \frac{LV}{\nu}$$

L = Projectile length - ft

V = Mean relative velocity between fluid and projectile - fps

ν = Kinematic viscosity of fluid - ft^2/sec

$$R_e = \frac{1.1 \times 30.25}{11.29 \times 10^{-6}} = 29.47 \times 10^5$$

II. Plotting

Date were taken with the model supported on a spindle which was protected from the flow by a shield. This was followed by similar runs with an identical image shield mounted opposite the spindle shield. The data were calculated for each run, the corrections were made for horizontal buoyancy caused by the working section pressure gradient, and the results were plotted, as in Fig. 12. Assuming that the difference caused by the addition of the image shield was the same as that caused by the spindle shield, this difference was applied to the No Image Curve to provide the CORRECTED curve.

III. Terminal Sinking Velocities in Sea Water at 60°F.[7]
(Based on Weapon A: Volume = 4.11 ft^3
Density = 117.6 lbs/ft^3)

Terminal sinking velocity is attained when the sinking force of the projectile equals its drag. The sinking force is the weight of the projectile in water. This is equal to the weight in air minus the buoyancy caused by the volume of water that is displaced.

Projectile Sinking Force = weight in air - (volume) x (density of water displaced)

= 483.3 - 264.5 = 218.8 lbs

Drag Force = $\rho/2\ C_D\ V^2\ A_D$

Equating and solving for V_T (terminal sinking velocity)

$$V_T^{\,2} = \frac{\text{Sinking Force}}{\rho/2\ A_D\ C_D}$$

Trial-and-error solution is required.

Assume V_T = 35 fps

$$R_e = \frac{6.88 \times 35}{12.64 \times 10^{-6}} = 19.05 \times 10^6$$

From Fig. 12, C_D = .166

$$V_T^{\,2} = \frac{218.8}{1.988/2 \times .855 \times .166} = 1549$$

$$V_T = 39.36 \text{ fps}$$

Assume V_T = 39.6 fps

R_e = 21.55 x 10^6

From Fig. 12, C_D = 0.164

$$V_T^{\,2} = \frac{218.8}{1.988/2 \times .855 \times .164} = 1568$$

V_T = 39.6 - Check

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